Temperature Dependence of Structural and Magnetic Properties of single-crystal CoCrFeNiMn-based Alloys

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Abstract

To study the Manganese (Mn) effects on magnetic properties of high entropy alloys (HEAs), we prepared a single-crystal $(CoCrFeNi)_xMn_{1-x}$ to eliminate the grain boundary effects. The samples with concentration gradients of Mn are sliced at different portions with different Mn contents. The magnetic and structural properties of $(CoCrFeNi)_xMn_{1-x}$ are examined as a function of temperature. We found that Mn content and magnetic properties have positive correlations. Our neutron diffraction data also show the Mn effect on the diffraction profiles.

Keywords: *high entropy alloy, magnetic property, in-situ neutron diffraction, crystal structure*

Introduction

High entropy alloys are multi-principal-element systems that can be crystallized as a single phase [1]. HEAs possess excellent mechanical properties [2] and corrosion resistance [3]. The mechanical mechanisms of CoCrFeNiMn HEAs have drawn extensively attention. Specifically, the microstructure evolution and phase transformation kinetics are not yet conclusive [4].

Moreover, the magnetic properties of HEAs show great potential for their good combination of performance and endurance [5]. Yeh *et al.* [6] reported the magnetic properties of $Al_xCoCrFeNi$ HEAs.

The magnetic properties of HEAs polycrystalline were previously reported by Lucas *et al.* [7] and Zhang *et al.* [8]. However, the magnetic properties of HEAs single crystals are still lacking and need to be explored [9] due to better uniformity of single crystal. In this study, we examine the evolution of magnetic and structural properties of single crystal $(CoCrFeNi)_xMn_{1-x}$ HEAs with different concentrations of Mn as a function of temperature.

Experiments

Co, Cr, Fe, Ni, Mn with purities of greater than 99.5% were used to prepare CoCrFeNiMn equimolar HEAs using a vacuum arc melting. Bridgman methods [10] were applied to the as-cast alloys to prepare single crystals CoCrFeNiMn HEAs.

After the single crystal CoCrFeMnNi HEA with Mn concentration gradients was prepared, it was sliced for different Mn contents, respectively. Three slices were selected as $(CoCrFeNi)_{88}Mn_{12}$, $(CoCrFeNi)_{91}Mn_9$ and $(CoCrFeNi)_{92}Mn_8$, respectively.

A superconducting quantum interference device magnetometer MPMS-XL (SQUID), was used to measure the magnetic properties of the samples, including the hysteresis loop (M-H curve) and the magnetization versus temperature curve (M-T curve).

In-situ neutron powder diffraction measurements were applied at Wombat neutron-powder-diffraction instrument of Australia's Nuclear Science and Technology Organisation (ANSTO).

Results

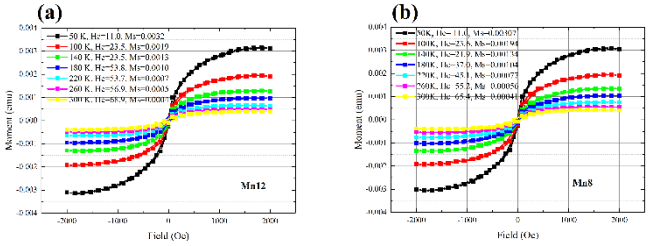

Fig. 1. Hysteresis loop of (a) $(CoCrFeNi)_{88}Mn_{12}$ and (b) $(CoCrFeNi)_{92}Mn_8$ at different temperatures.

Figs. 1(a)-(b) describe the magnetic properties of $(CoCrFeNi)_{88}Mn_{12}$ (Mn12) and $(CoCrFeNi)_{92}Mn_8$ (Mn8) specimens, respectively. The Curie temperatures (Tc) of $(CoCrFeNi)_{88}Mn_{12}$ and $(CoCrFeNi)_{92}Mn_8$ were calculated to be 296 and 303 K, respectively, by the Bloch's law fitting [11]. $(CoCrFeNi)_{88}Mn_{12}$ and $(CoCrFeNi)_{92}Mn_8$ become the paramagnetic above Tc.

The initial saturated moment (M_0) of $(CoCrFeNi)_{88}Mn_{12}$ was also calculated by Bloch's law fitting to be 2.58×10^{-3} emu, which was higher than 2.55×10^{-3} emu of $(CoCrFeNi)_{92}Mn_8$. In addition, the coercive field strength (H_c) of $(CoCrFeNi)_{88}Mn_{12}$ was higher than that of $(CoCrFeNi)_{92}Mn_8$ in the temperature range from 50 K to 300 K, indicating stronger magnetic properties of $(CoCrFeNi)_{88}Mn_{12}$ than $(CoCrFeNi)_{92}Mn_8$.

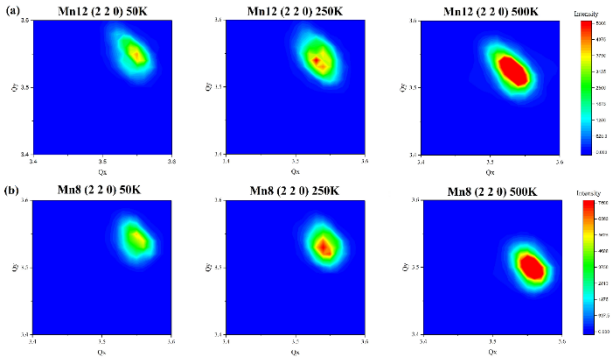

Fig. 2. 2D in-situ neutron powder diffraction patterns of (a) $(CoCrFeNi)_{88}Mn_{12}$ (2 2 0), (b) $(CoCrFeNi)_{92}Mn_8$ (2 2 0) at various temperatures.

Fig. 2(a)-(b) depict 2D diffraction patterns of (2 2 0) in $(CoCrFeNi)_{88}Mn_{12}$ and $(CoCrFeNi)_{92}Mn_8$ from low to high temperatures.

As Fig. 2(a) shown, there is only one major peak in the center in (2 2 0) diffraction pattern of $(CoCrFeNi)_{88}Mn_{12}$ at 50K. At room temperature, the main peak is still in the center but disperses to three distinct peaks which combine to become the only one peak at 500K. The intensity increases with the increasing temperature.

On the other hand, in the case of (2 2 0) diffraction pattern in $(CoCrFeNi)_{92}Mn_8$ in Fig. 2(b), there is only one peak at low temperature. This peak remains unchanged during the variation of temperature, suggesting the single peak effect of (2 2 0) in $(CoCrFeNi)_{92}Mn_8$.

Discussion

In 2006, Yudurian *et al.* [12] published a study of the relationship between stacking fault energy (SFE) and magnetic properties. The effect of Mn on SFE was reported by Huang *et al*. in 2015 [13]. It implies that: (i) the formation of stacking fault may lead to the increase of magnetic moment; (ii) the greater amount of Mn in the samples, the higher saturated moment the samples possess. In our samples, the initial saturated moments of $(CoCrFeNi)_{88}Mn_{12}$ and $(CoCrFeNi)_{92}Mn_8$ are 2.58×10^{-3} and 2.55×10^{-3} emu, respectively, which agrees with previously proposed results. In addition, the magnetic properties variation of $(CoCrFeNi)_{88}Mn_{12}$ and $(CoCrFeNi)_{92}Mn_8$ suggests that $(CoCrFeNi)_{88}Mn_{12}$ possess more stacking fault than $(CoCrFeNi)_{92}Mn_8$.

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